Integration of Outcrop Studies to Naturally Fractured Subsurface Models – Example of the Mogollon Formation, Block X, Talara Basin, Peru*

Jul D. Roldan Guevara[1], Diego Eduardo Escobedo Cabrera[1], Alan Patrocinio[1], Eloy Gerardo Pozo Calle[1], Percy G. Manrique Caceres[1], and Lucio Choque Arivilca[1]

[1]PETROBRAS, Lima, Peru (julroldan@gmail.com)

Abstract

The aim of this work is to establish a methodology for generating naturally fractured reservoir models in 2D and 3D. It integrates outcrop data, core data, images logs, structural maps and production information. The study was conducted in the Peña Negra Area, Block X in the North West of Peru, where main structural framework is the extensional tectonic style.

From the natural fractured outcrop data (orientation, geometry, intensity, etc) and a theoretical scale structural model the distribution of the fracture systems was determined. In addition, it defined and quantified the relationship between faults and adjacent natural fractured zones. Three conjugate fracture systems were identified. A set of equations were established for these three systems and they can be used as an input for stochastic fracture model generation in any commercial software and 2D fracture density map.

There are 25 wells, few cores and image logs in the area. The study includes the identification of the main characteristics of the fractures (classification, wide, orientation) and it establishes a relationship between lithology and fracture density. As result of this study, a fracture volume was obtained. From petrophysical interpretation, high and low permeable sandstones were discriminated to associate high permeability sandstone to the matrix OOIP.

The dynamic analysis used an empirical methodology to estimate OOIP in fractures. Wells with high production cumulative in short time were considered to produce from fracture zones. The production cumulative from fractures was obtained from the difference between total cumulative and matrix cumulative, the last one coming from a production type of curve for each well.
It is concluded that fractured systems are associated to a fault systems in extensional tectonic style, in their structural position and orientation. In addition, fracture volume and 3D stochastic fractured network were obtained.

Introduction

Mogollon Formation in Block X during reservoir production history has presented sufficient arguments to be considered a naturally fractured reservoir. The shortage of well information, cores and logs image did not allow an adequate characterization of fracture systems. The goal at this point in the field is to have a nature fracture model, which integrates the existing geological models in the area such as stratigraphic, structural, petrophysical, dynamic and production analysis in the Pilot Zone with outcrop's information analogous. An adequate characterization of natural fracture systems will allow to have better planning for the development of reserves considered naturally fractured reservoirs (NFR) in Block X.

Location

Block X is located in the Talara Basin to the North-west of Peru (Figure 1), begins its productive development in 1910, which means that the area is being exploited by nearly 100 years. It is characterized by multi-light oil reservoirs (API=36), with solution gas mechanisms. Over 5300 wells have been drilled to December 2012 and collecting around 467 MM barrels of oil. More than half of them are currently active. The "Zona Piloto" is located in Block X and the fieldwork was development at 30 km southwest of the "Zona Piloto" in the Salado and Mogollon streams, located 18 km northwest of the city of Talara, where the Ostrea and Mogollon Formation are outcropping (Figure 2). Within the plurality of reservoirs is the Mogollon Formation (Middle Eocene), which is a deposit of siliciclastic in a depositional environment Fluvial with NE-SW orientation and exhibits porosity and permeability ranges from 5-6%, and 0.01 to 0.1 mD respectively. The main reason for the low reservoir quality is the occurrence of numerous diagenetic episodes has affected the rock, among which we mention the following: calcareous cementation and siliceous cementation and clays overgrowth. Figure 3 shows the electric log type and the main petrophysical characteristics of Mogollon Formation (Figure 3).

Cores and Special Logs

In the "Zona Piloto" are three cores with over 200 feet continuous of sample recovered, which have basic petrophysical studies and lithological description, a count of open a close natural fractures was made in which take the average value of aperture in closed fractures, the value obtained was 1.5mm (Figure 4). The description corresponds to a section composed dominantly of overlapping sand bodies, interpreted as mouth bars, reservoir quality controlled by high mechanical compaction of sedimentary rocks, other primary drivers pore volume and reservoir quality are detrital clays in the matrix, moderate calcareous cementation and calcareous cementation in stains. The poor quality sandstones dominated by microporosity (2%-5%) which is related to the authigenic clays, especially chlorite. Better quality sands are related to primary intergranular porosity (0%-3%) and secondary porosity by dissolution (tr-2%) as part of the pore system, there are open natural fractures (1 mm – 2 mm) that are not detected by traditional logs, there are natural fractures closed and mainly filled with calcium carbonate. Later a connection between the existence of open a closed fractures with lithology described was established (Figure 5).

Special Petrophysics

The established petrophysical interpretation of the well in the "Zona Piloto" mainly focused on differentiating sands with low permeability getting two different thicknesses of net sand. This methodology within a conventional evaluation is to improve the vertical resolution of the SP and then generates a VCL curve from SP curve, which is used as a new parameter petrophysical discriminant for reports (Figure 6, Table 1).

Structural Analysis

The Talara Basin as a whole presents a structural complexity whose subsurface and outcrop interpretations shows: abundant fractures and faults; testimony of a multiepisodic tectonics with moderate intensity magnitude. Several generations of faults and fractures with different directions have been identified and which have been subsequently reactivated as extensional faults mainly (Figure 7). Structural maps are made at the level reservoir and represent known surfaces and validated by the existing wells, the spaces between the blocks show the magnitude of the extensional tectonic events (Figure 8).

Experimental Theoretical Support

A structural scale model based on the structural map in order to simulate the tectonic events that produced the extensional structure, for the experiment was made a wooden box and glass, which is filled with clay and sandstone in order to simulate the stratigraphy in the area. Extensional was simulated by means of separating the inner walls generating space corresponding to 20% of the structure with a constant motion, a considerable weight exerted greater effort function at the top to reconstruct the tectonic event. The configuration of the structural model in the blocks was tailoring according as the space is increased by the extensional, finally coming to have as similar structure as the structural sections of the zone (Figure 9). This experiment was able to verify that the structural configuration is dominantly tectonic and small structures are the key to mimic the styles and orientations of large structures when these are generated by the same tectonic event within a particular area. This 20% space generated has caused a collapse of the existing structures; it has been generating Horst and Grabens where the center and the edges have maintained their initial position. The tectonics shows that block movements (faults) are fractures at the beginning and then starts its move because of space increase produced by the action of the overlying effort during the period of extension. These events generate faults and fractures in conjugated systems. Therefore, the fracture systems are associated with the fault systems structural position and orientation. Besides the sunken blocks, they have more fractures than non-displaced or uplifted blocks.

Outcrop Information

Field studies was made to South of the "Zona Piloto" in the Mogollon and Salado stream where the rocks are outcropping, upper Mogollon Formation in contact with Ostrea-Palegreda are been showing. The Mogollon Formation has been interpreted by the studies as a fluvial environment with energy loss to the uppermost. Presents proximal facies: characterized by heterolithic conglomerates, middle facies: mainly composed of medium to coarse-grained sandstone with the presence of gravel, presents of festoon and cross lamination, distal facies: characterized by fine to medium-grained sandstone with sigmoidal cross lamination and towards the top presents plane parallel lamination

(Figure 10). A detailed geological map in the ravine was generated, the main structural features was identified in order to have a better understanding of the structural and stratigraphic settings of the area. Faults were identified to measure and associated fracture systems, they was divided into parallel, perpendicular and oblique. Fractures caused by external geodynamic agents in the outcrops are not considered for these measurements (Figure 11).

Data Acquisition Fractures

The methodology consists in the information acquisition of fractures associated fractures along a section perpendicular to the strike of the fault in the same stratigraphic unit, the data reported are amount, direction and length of each fracture. This new methodology was adapted to the complexity of Talara field due to accessibility, exposure of the outcrops and faults (Figure 12). The complete methodology includes in sequence: a) detailed geology (field); b) acquisition of fractures information (field); c) selection of information (cabinet); d) correction data and calculations; and e) statistical analysis and interpretation. A mathematical model for fracture systems associated with fault is postulated from the conclusions.

In the stereographic projection diagram of Figure 13 the red line identifies the direction and dip of the fault 01. The dash gray lines in the directions and dips plane of the layer 01 in both blocks, these points represent the stereographic projection of natural fractures which may be associated in families. The colors are highlighted in the table for families (Figure 14). Some fault field measurements without sections perpendicular to the direction of exposed fault, it is opted to make a diagram in office to make corrections in order to find the true values (Figure 15).

Generation of Fracture Density Model

Fracture density was calculated from the generated diagram, using the formula:

$$DfracA - Longitud\ Frac\ /\ Area\ Medida$$

A relationship between the number of fractures seen in the field, and the areal fracture density is determined by the chart in Figure 16; it has considered tentative relationships for different lithologies. The relationship between the number of fractures and the fault distance allowed the generation of theoretical mathematical models. There are 6-order polynomial formulas for different cases of the structural complex. These relationships represent the value of fracture density for points aligned perpendicular to the fault directions via a spreadsheet generation where the control points are well data (Figure 17).

This structural distribution has been represented in the pilot block of Peña Negra field, which is bounded by fault bigger than 600 feet of faulting and has a minor system of faults in the order of 100 feet inside the block (Figure 18). Finally, set of fractures were generated using stochastic simulation based on the fracture density maps. Three fracture systems represented are based on 3D structural model (Figure 19). The input for this fracture network is the density map for each stratigraphic unit, string maps for orientation, aperture is the average for closed

fractures measured in cores and length is the value obtained in outcrop. Before obtain the volume oil in place deterministic for matrix and fractures them these values were compared with the dynamic analysis.

Dynamic Analysis

A dynamic analysis of wells in the "Zona Piloto" was performed. The empirical methodology gathers wells with similar chronology in graphics of production percentage over time. It identifies groups of wells with equal percentages accumulate in the same period, suggesting heterogeneity and amount of similar fissures. The "Zona Piloto" contains 25 wells. The production started in 1959. The last well was drilled in 1997, so that only 17 wells were used for the study. Normalization of the cumulative production was performed even more the grouping shows three types of behavior the first 24 months (Figure 20).

The average production curves were worked for each of the 3 types. These averages confirm dissimilar behavior even if have similar petrophysical characteristics and similar completion of production. The difference is in the number of fractures present and connected to each other. For this reason these behaviors were mapped, it allowed to obtain areal trends as shows in the Figure 21.

The methodology suggests that a homogeneous reservoir without the presence of fractures should behave with a constant slope and similar for all wells. The diversion of the slope represents heterogeneity levels that can be quantified by the percentage of the contribution of matrix and fractures. For this curve was constructed 100% matrix for each of the three types of behavior and compared individually with each grouping of wells. The difference between both gives an indirect indication of the productive contribution by natural fractures. The results are shown in Table 2.

In the same way, in the production curves of the "Zona Piloto" is observed with these values that the types of behavior are independent of each other during the early years (Figure 22). Additionally, studies of numerical simulation are underway to verify these input values considering the new model of nature fractures. This study expect to quantified impacts and uncertainties of spacing, aperture, fracture distribution and connectivity. In turn, identify areas with matrix less drained and the productive potential interference caused by the fractures network.

Calculation of Volumes

The calculation of matrix and fracture volumes (Figure 23 and Figure 24) was performed separately for data wells cores, fracture density maps and the 3D model, these results were compared with those obtained by the dynamic method to reach have a first idea of the contribution of oil from fractures in the block. The storage capacity of the fracture systems is among 8% and 13% of the "Zona Piloto" volume is determined, being the first approach and considering still debatable. Based on this comparison with the work published by Ronald A. Nelson, the Mogollon Formation would be in a system where our fracture contributes less than 0.5% of the system volume.

Conclusions

This work established a methodology integrating outcrop studies to generate natural fractures models 2D and 3D, for the Mogollon Formation in Block X in the Talara Basin, based on the following considerations:

- The domain of the structural model for the distributing of fractures families was determined.
- The relationship between lithology, number of fractures in the cores and special registers was established.
- The relationship between the number of fractures and fractures density was established in the field.
- The theoretical model is ascertained. The fracture systems are associated as both structural position and orientation.
- Volume reservoirs qualitatively more permeable are established by means petrophysical interpretation.
- The first model discrete of fractures for the block that is obtained to be subsequently evaluated with the dynamic information.
- First approximations of the volume produced by fractures to the "Zona Piloto" are obtained.

Acknowledgements

Reference Cited

Nelson, R.A., 2001, Geologic Analysis of fractured reservoirs: Second Edition, 352 p.

Figure 1. Location map of the Talara Basin, northwest of Peru.

Figure 2. Location map of the "Zona Piloto" and outcrop area.
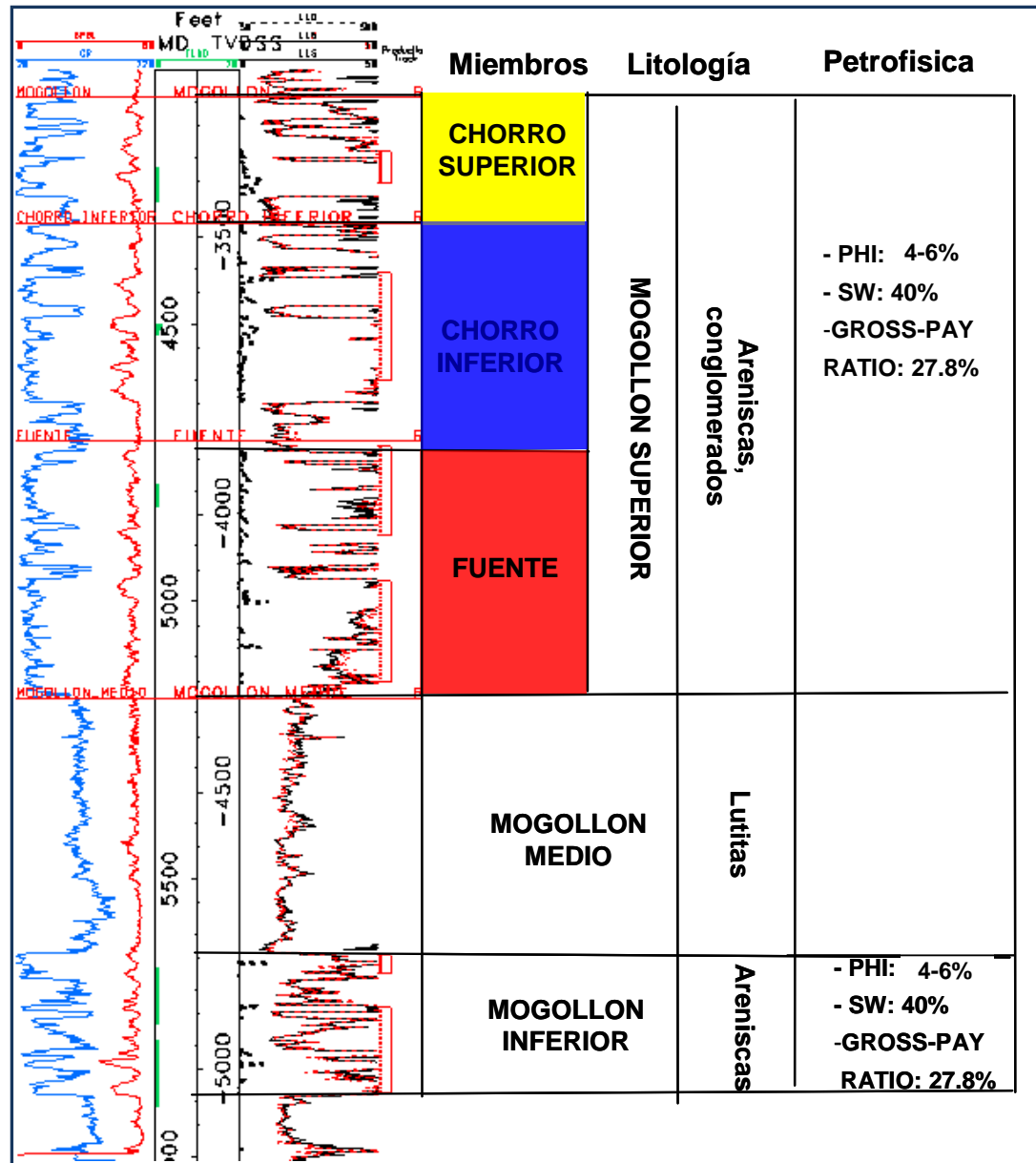
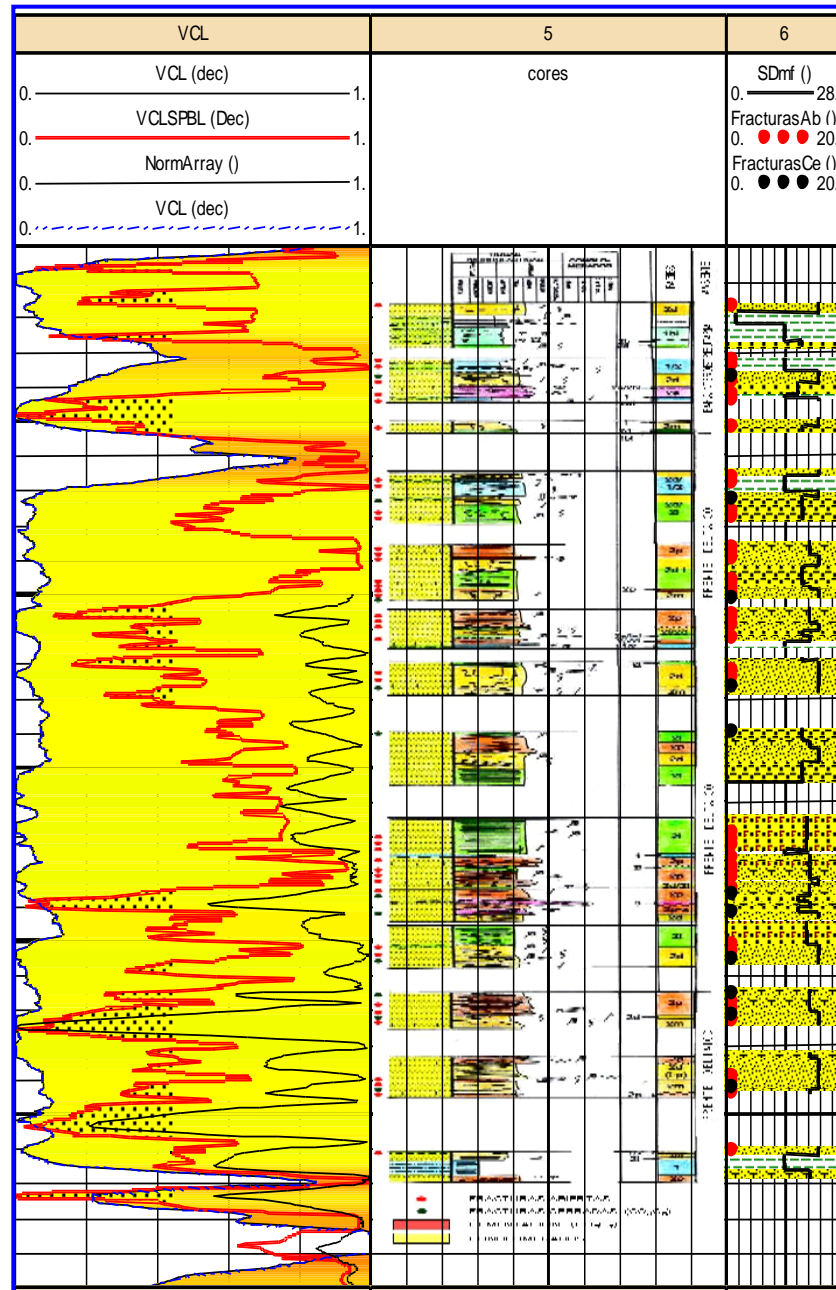Figure 3. Type Log and principal petrophysics characteristics.

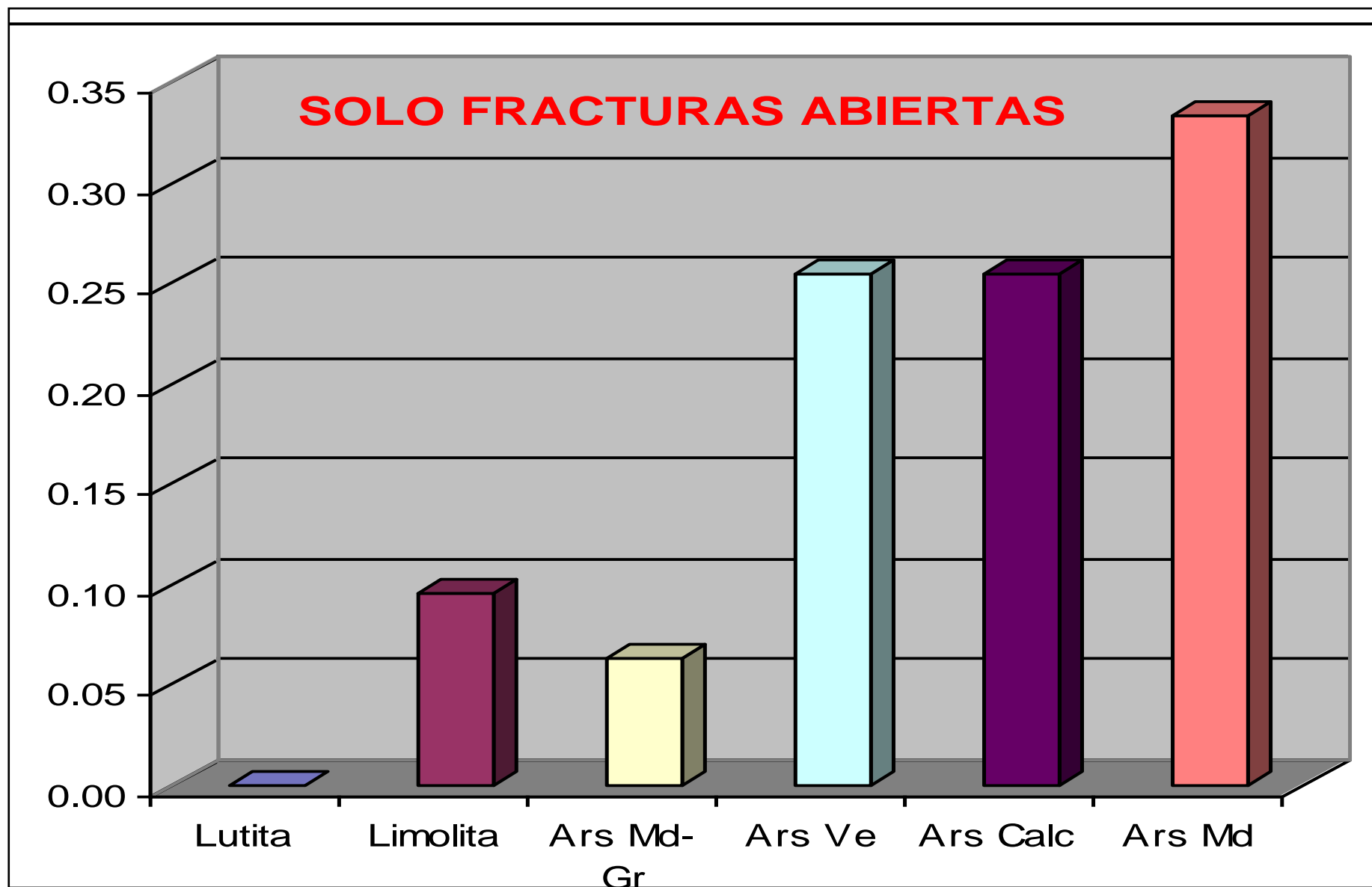Figure 4. Log showing VCL vs. VCLSP with core information.

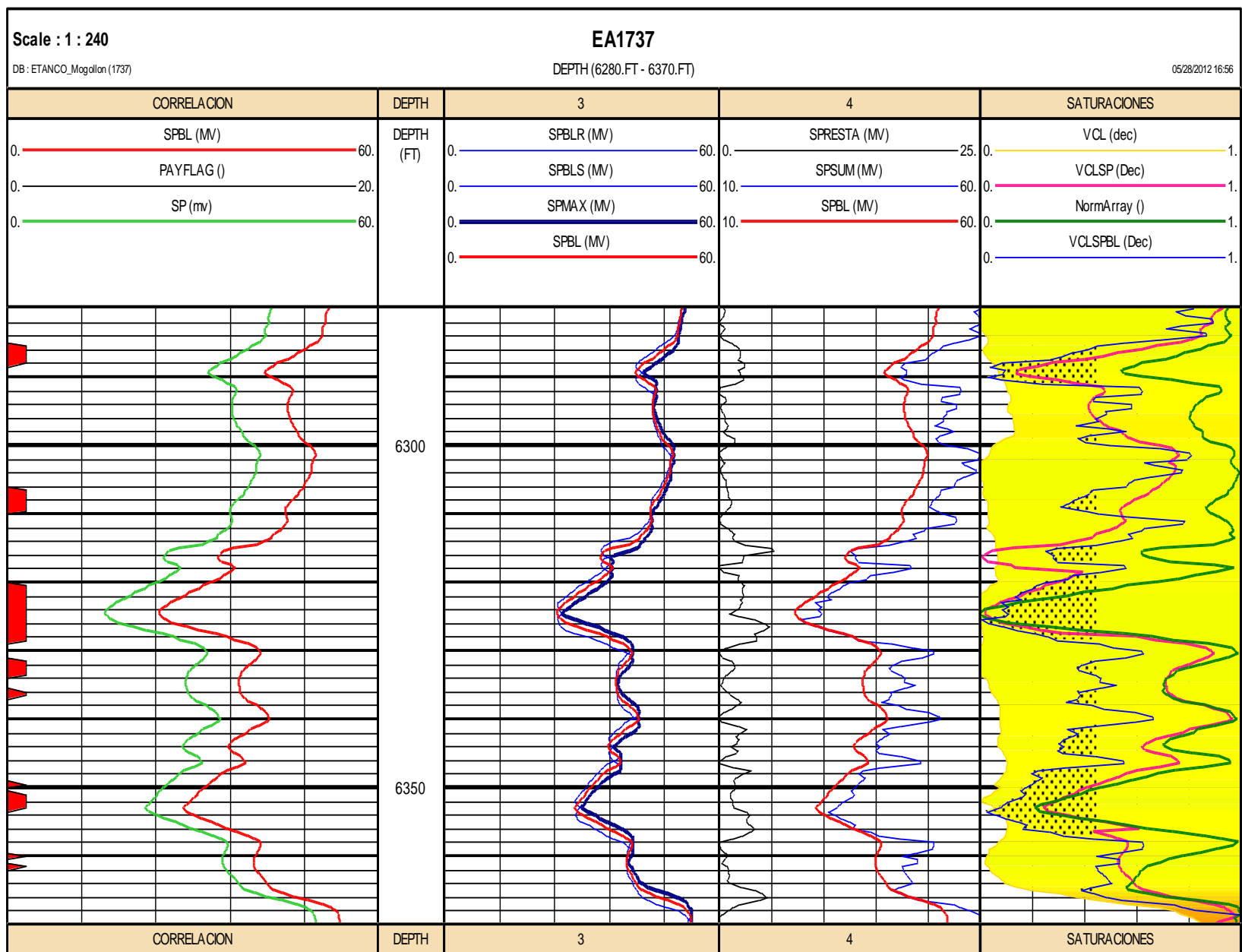Figure 5. Histogram for open fractures in different lithologies.

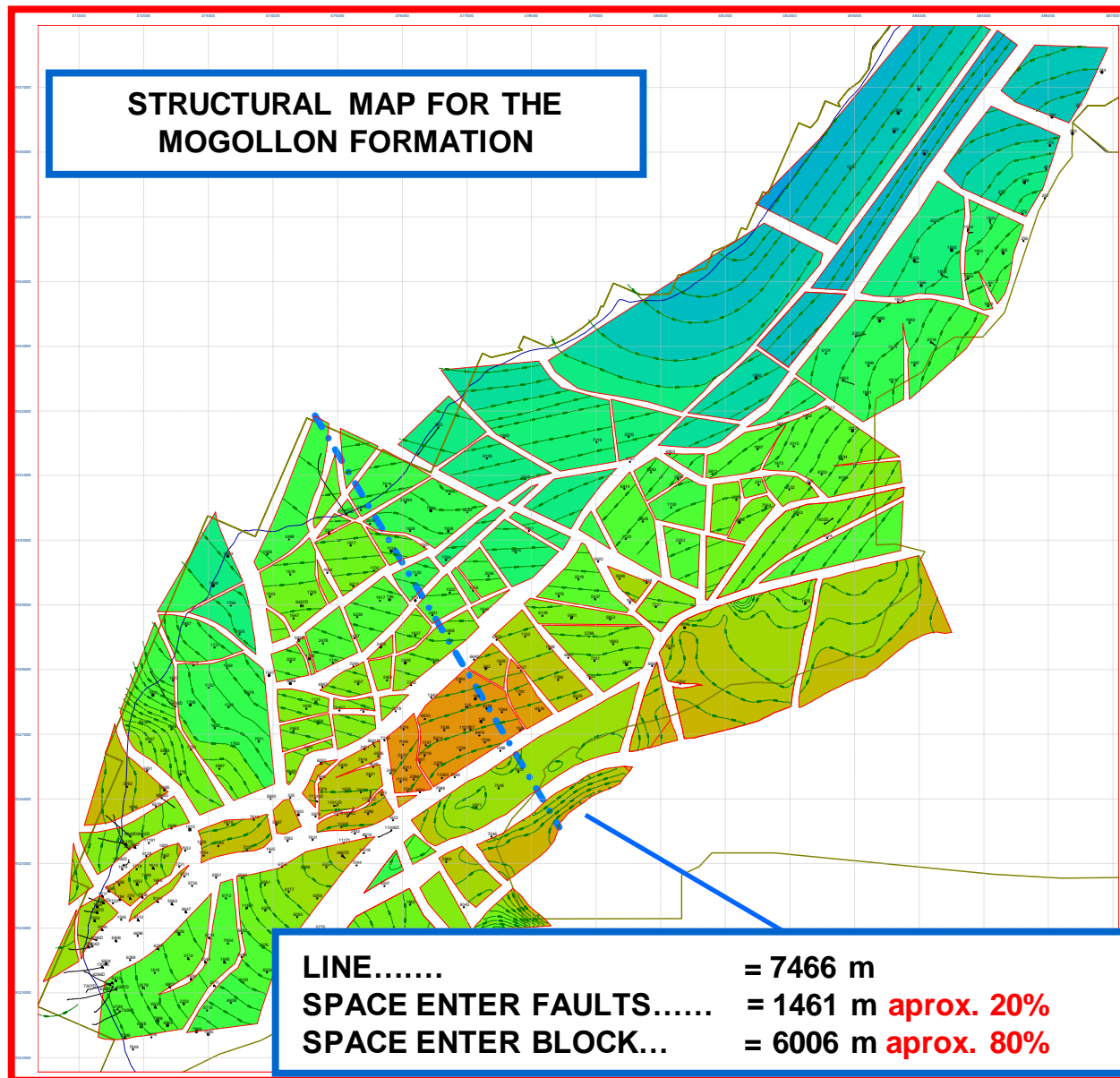Figure 6. Re-processing to SP log and comparison VCLSP with VCL.

Figure 7. Principal string maps with images, caliper logs, and fault directions.

STRUCTURAL MAP FOR THE
MOGOLLON FORMATION

LINE……. = 7466 m
SPACE ENTER FAULTS…… = 1461 m aprox. 20%
SPACE ENTER BLOCK… = 6006 m aprox. 80%

Figure 8. Structural map at top of Mogollon Formation.

Figure 9. A structural scale model for different times during the experiment.
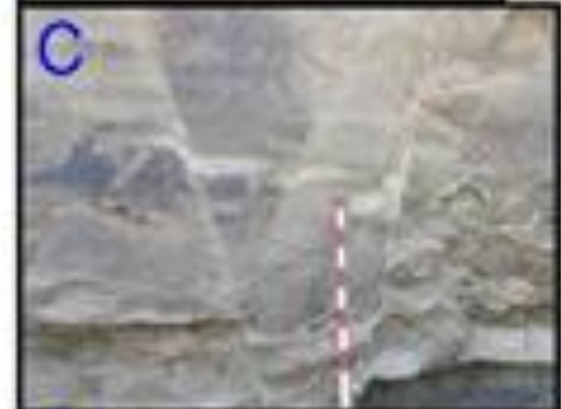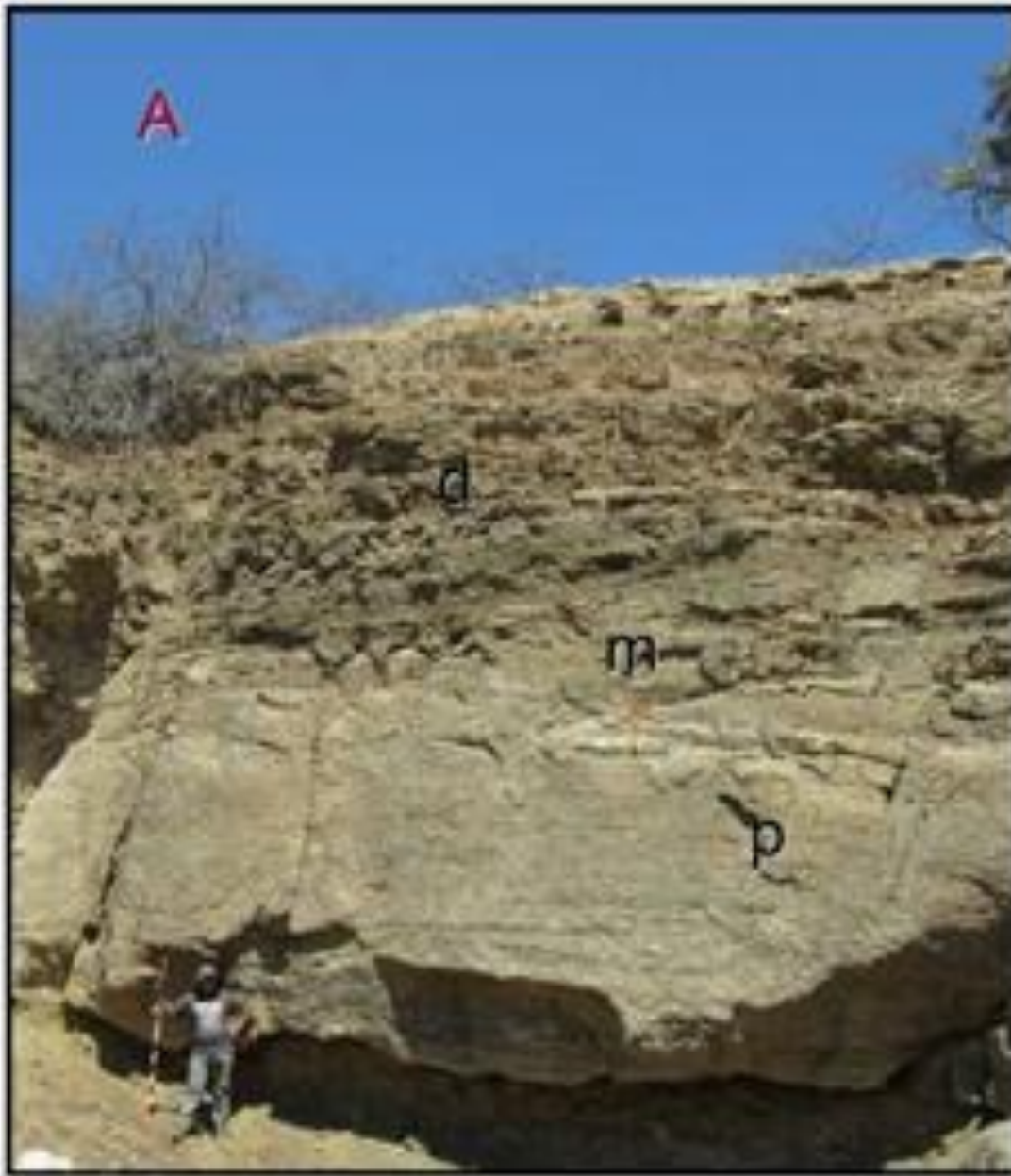
Figure 10. Outcrop with proximal (p-B) middle (m-C) and distal (d–D) facies.
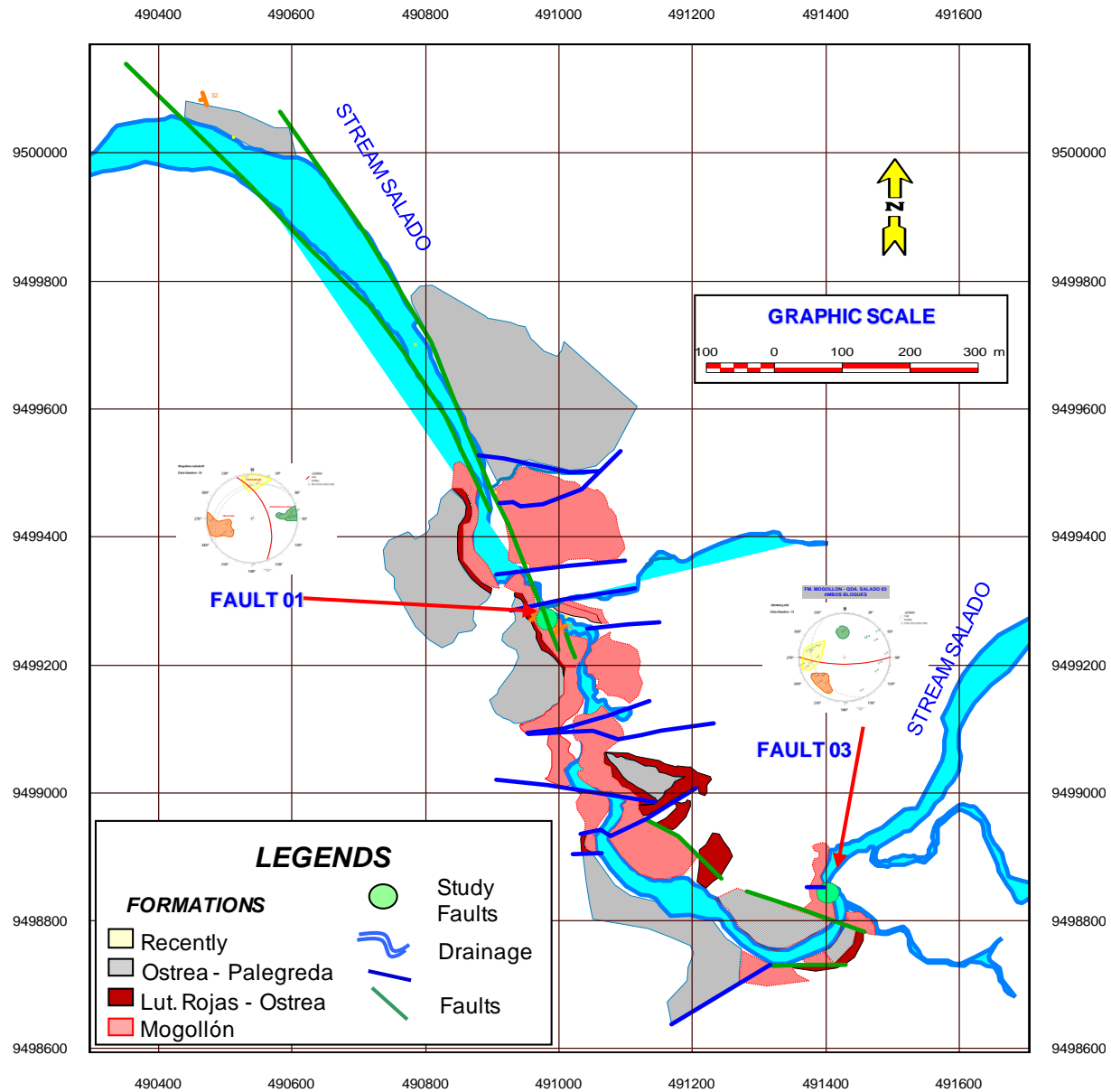
Figure 11. Geological map - Salado stream.

Figure 12. Fault 01, Salado stream, Mogollon Formation, Sandstone fine-grained, massive. Location WGS84 Zone 17: E 491 001 - N 9 499 272.
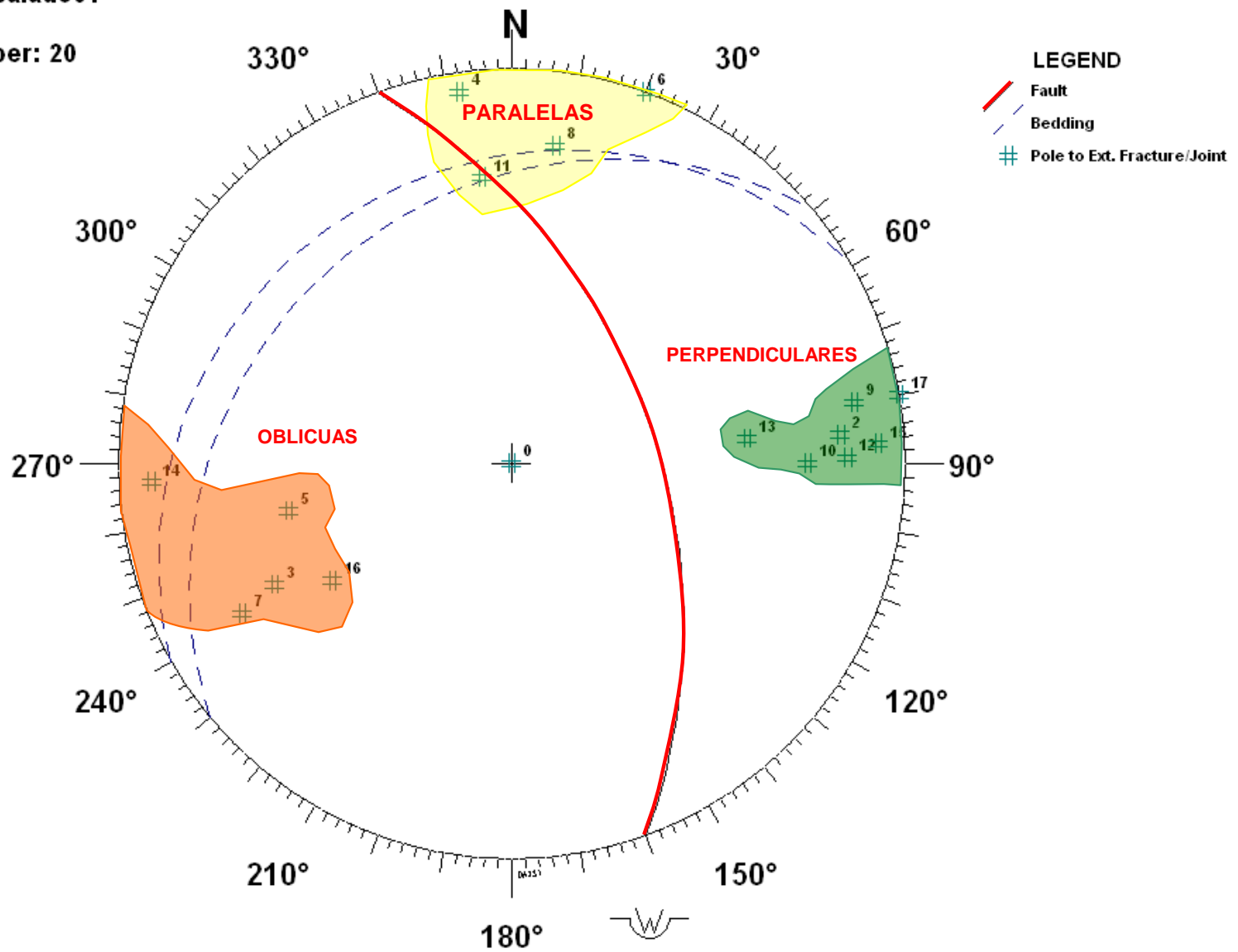
Figure 13. Strike and Dips for fault 01.
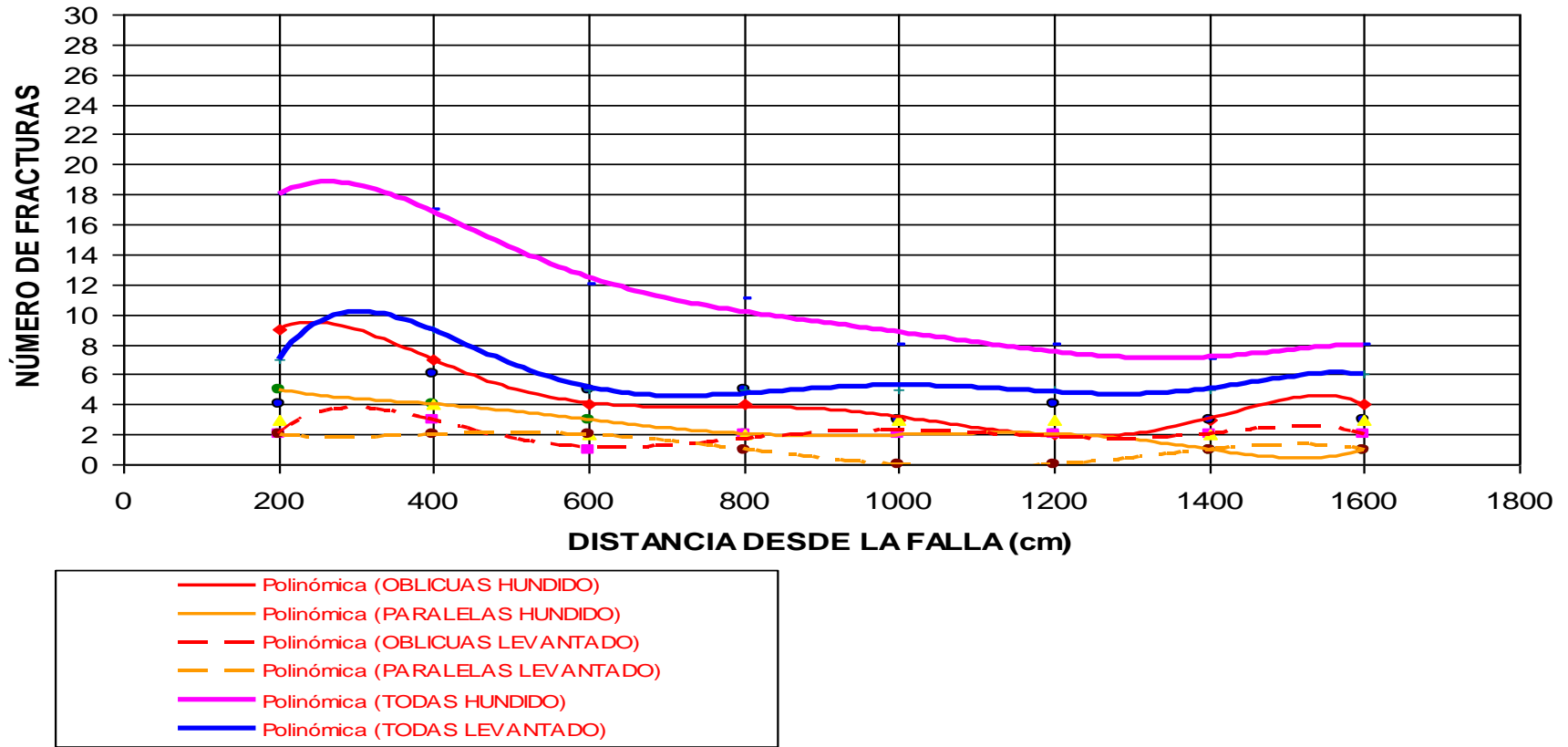
Figure 14. Fracture density and its relationship with distance to fault.

BLOQUE LEVANTADO

BLOQUE HUNDIDO

Salto de 15 m

Espesor de la capa03 430cm

Distancia a la falla en cm

DIST. A LA FALLA CM.	1400	1200	1000	800	600	400	200	F A L L A	200	400	600	800	1000	1200	1400
# FRACTURAS	6	4	5	7	9	10	12		8	6	5	3	4	3	2
# CRUCES	4	2	6	7	14	18	18		12	1	0	0	2	0	0
LONGITUD DE FRACTURAS CM.	1237	950	1028	1422	1759	1847	2451		1153	1100	2020	960	950	608	430
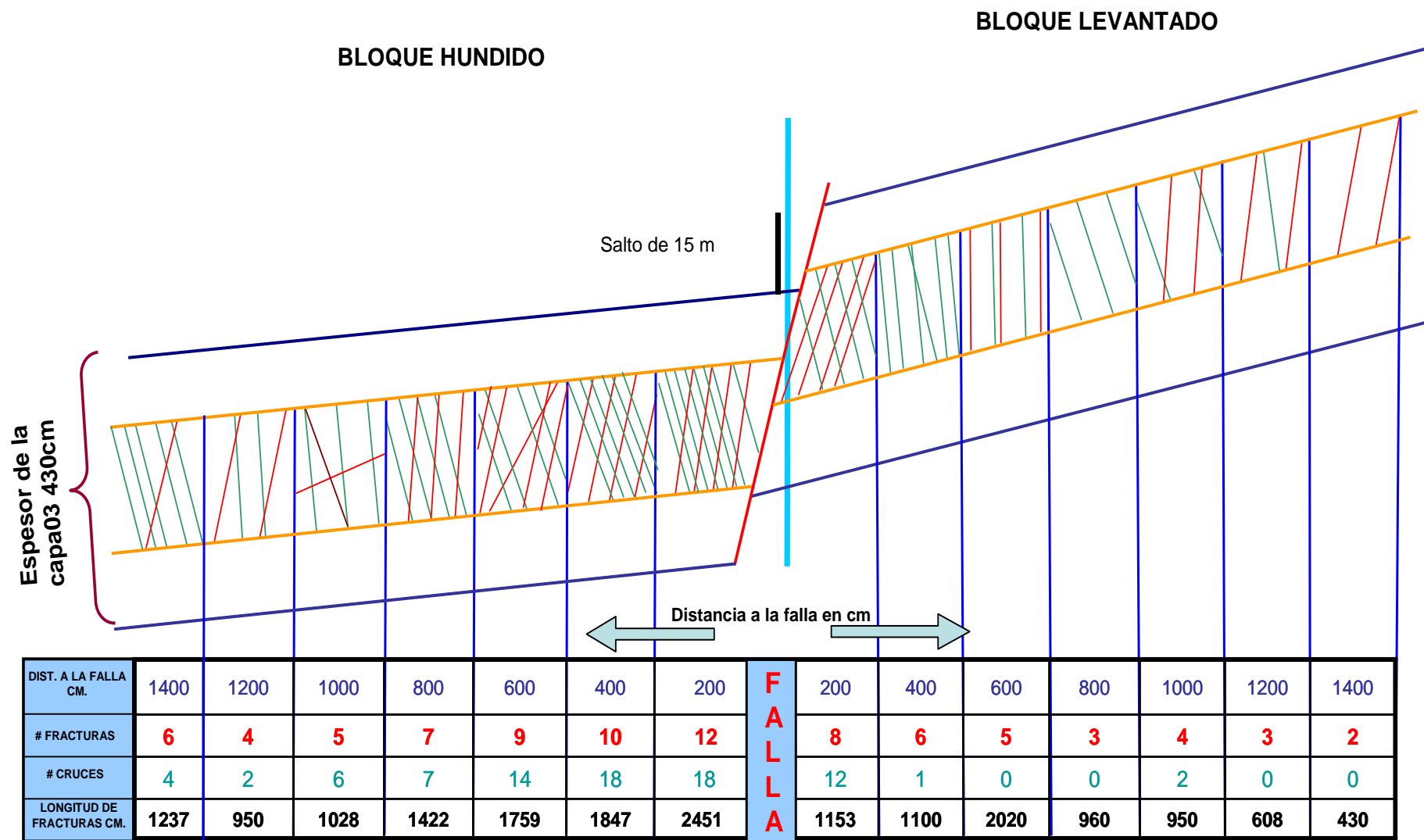
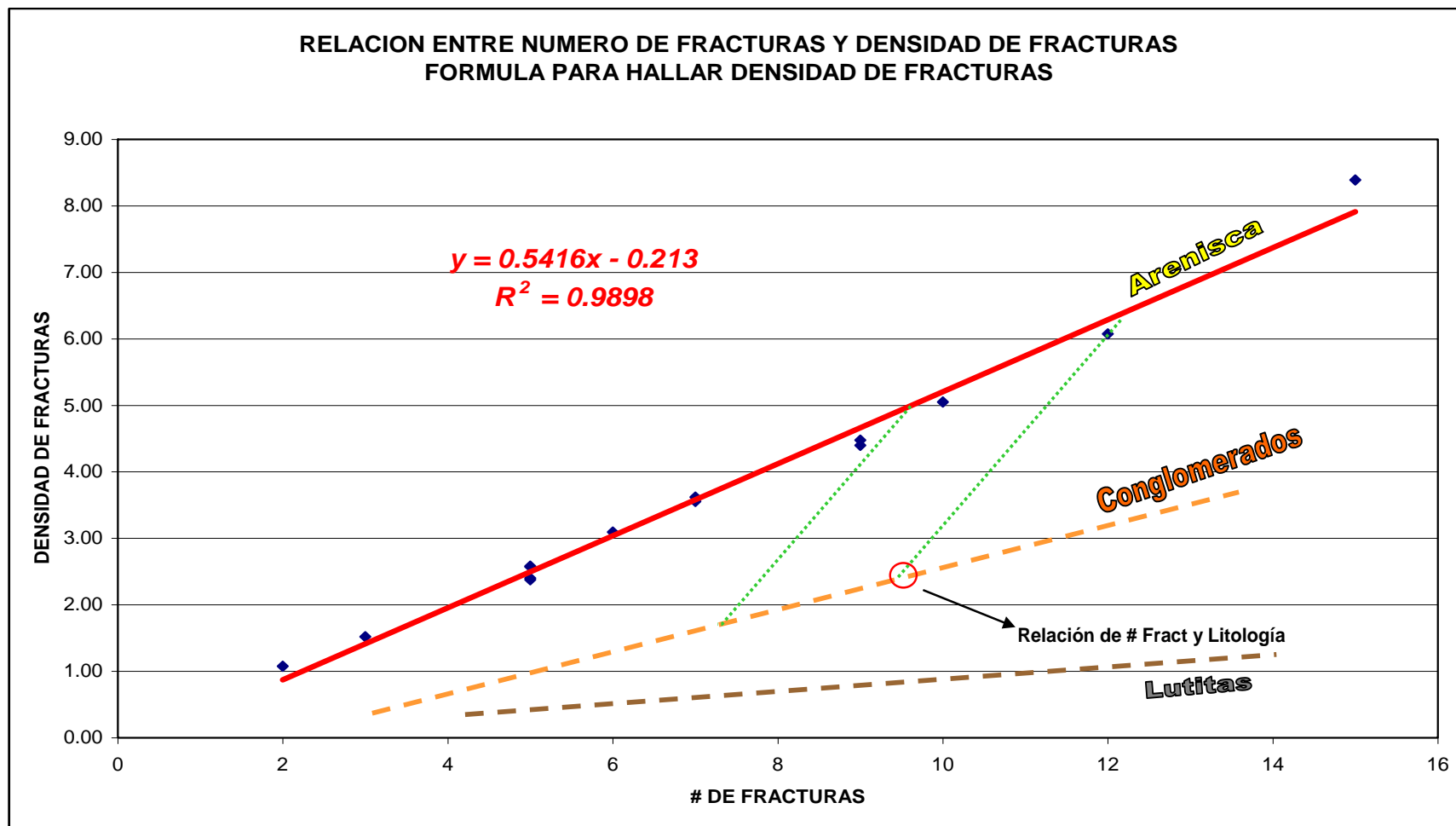Figure 15. Correction for measured section and diagram of the length and areal density.

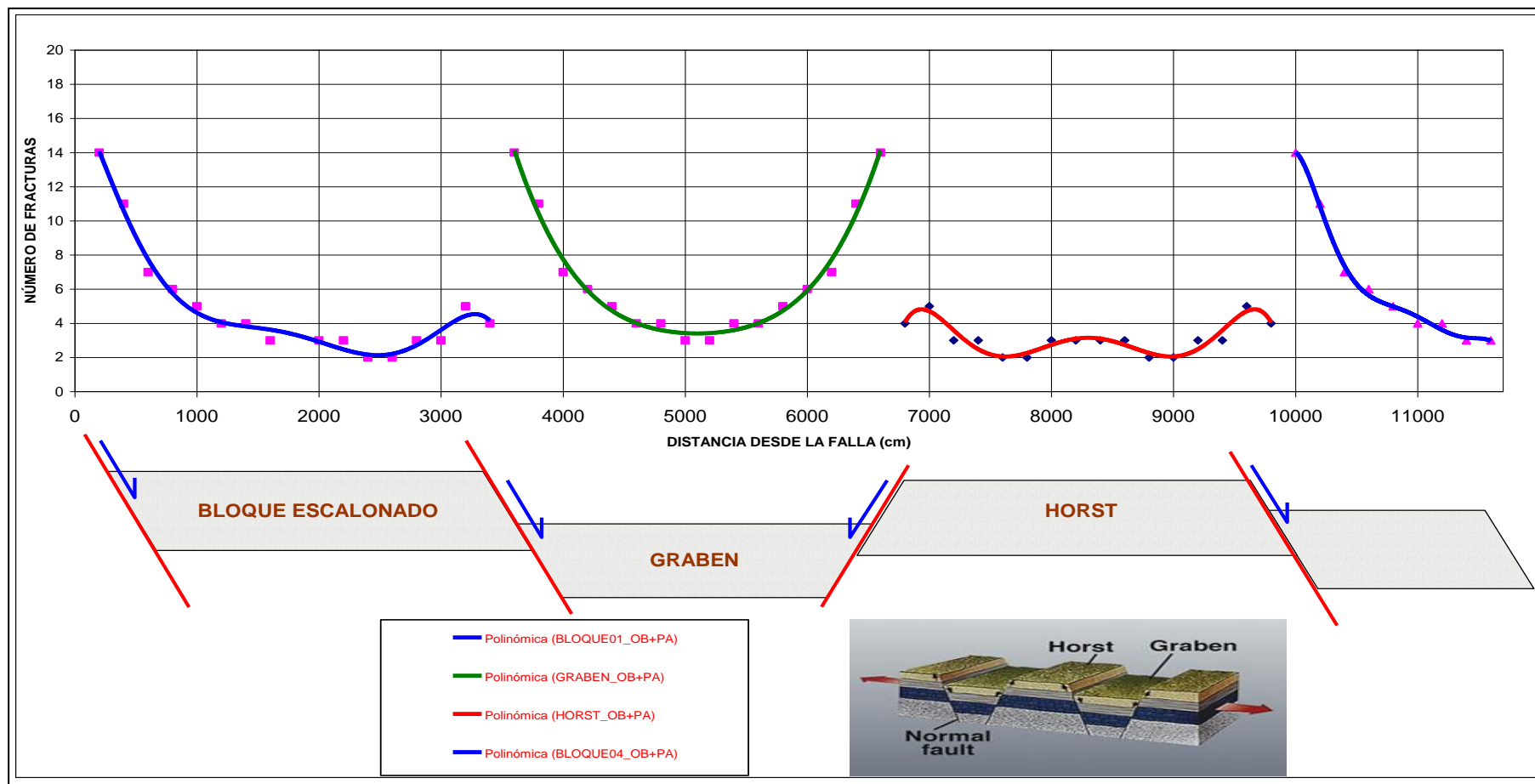Figure 16. Fracture counts in relationship with fracture density for different lithologies.

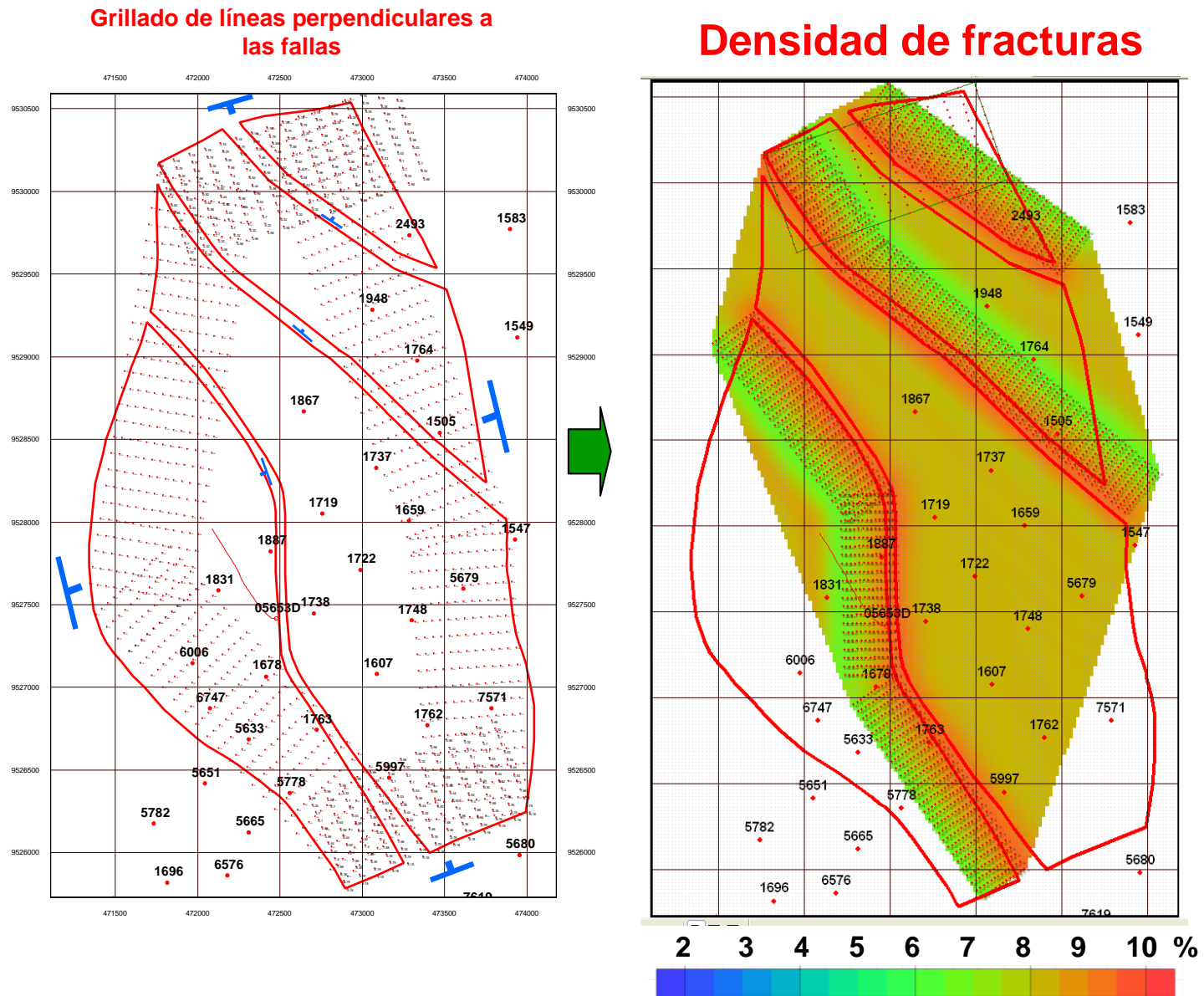Figure 17. Fracture density distributions for different structural positions.

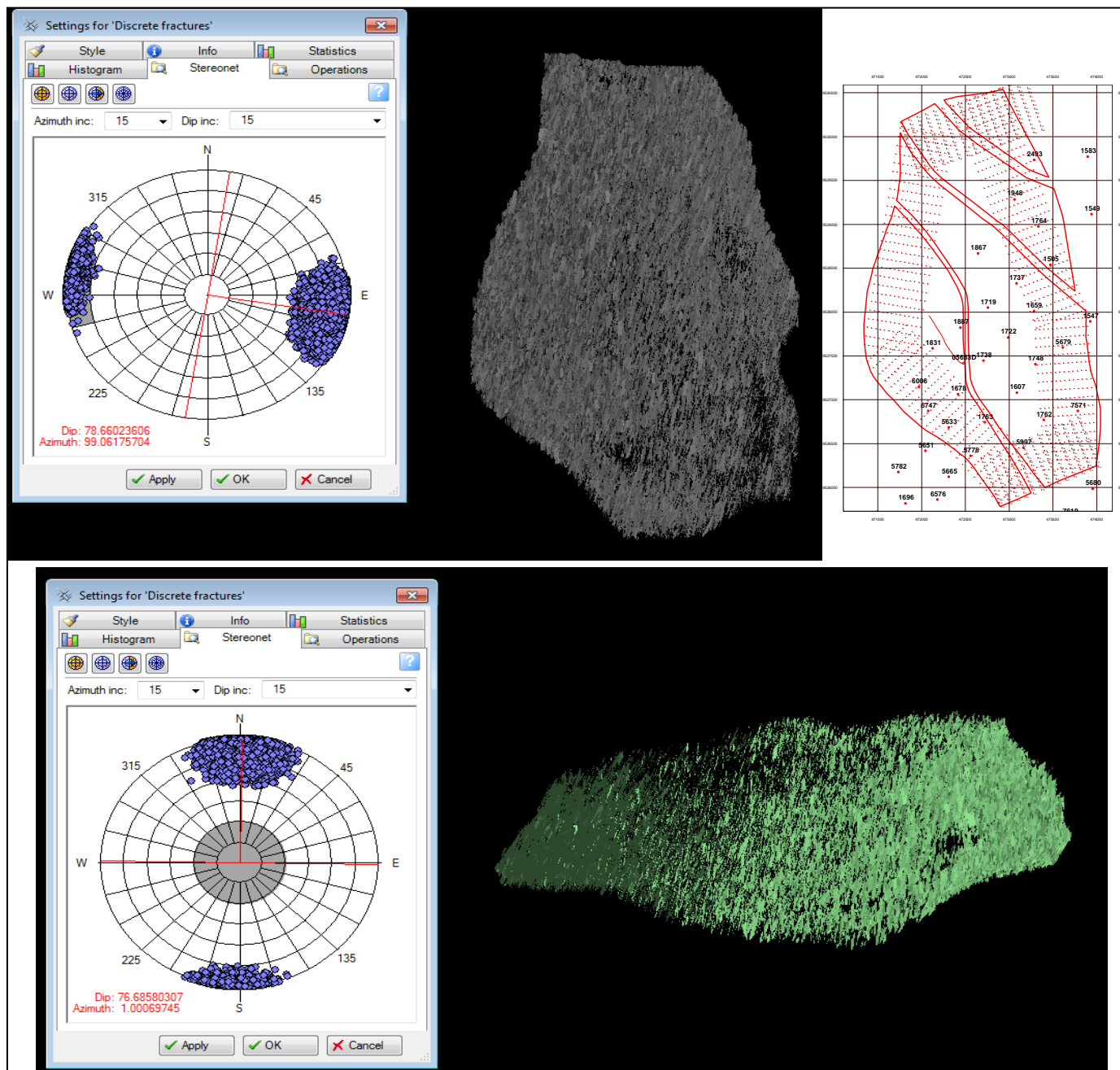Figure 18. Grid for fracture density distribution and density map for the third set of natural fractures.

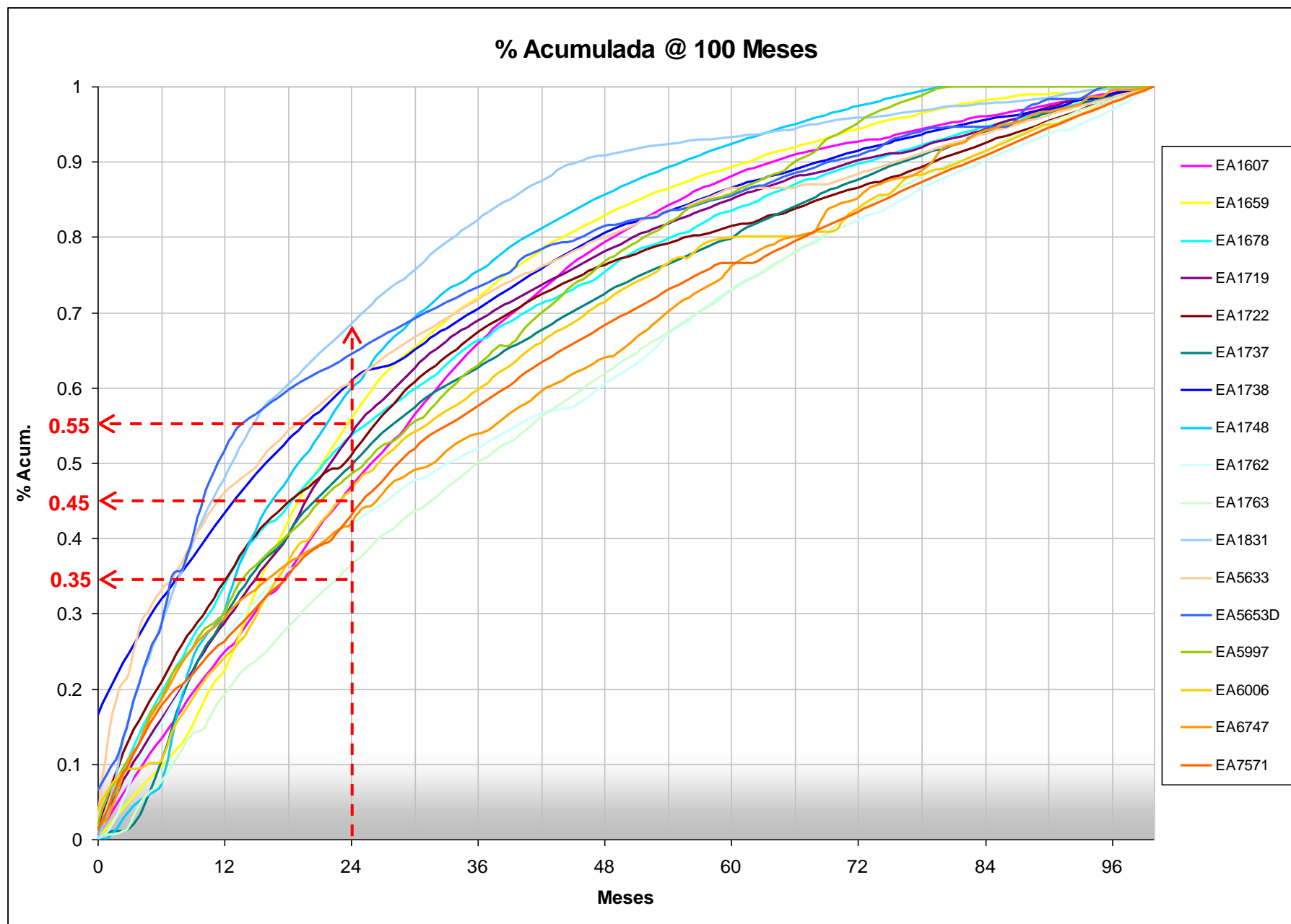Figure 19. 3D generation for the natural fracture network.

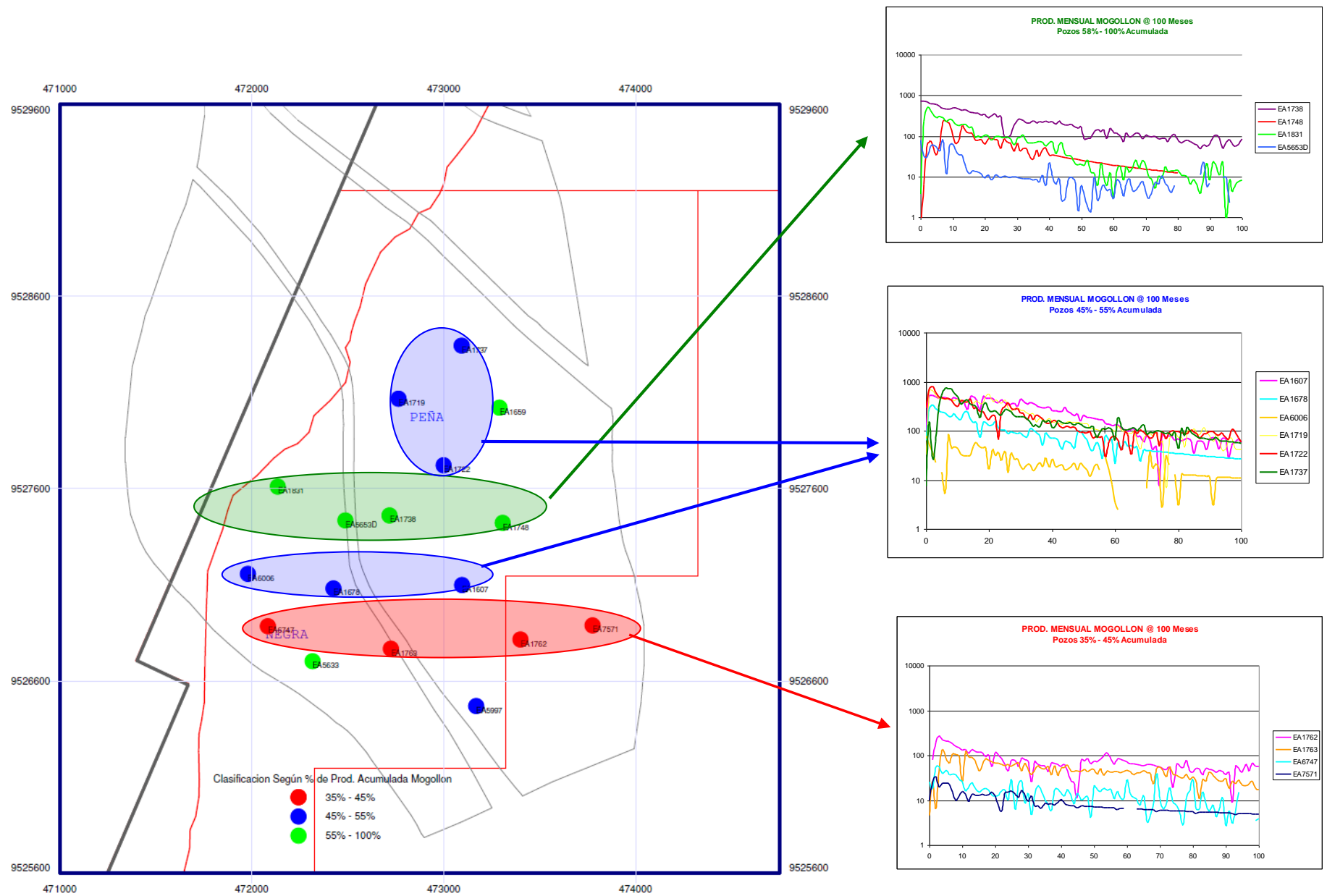Figure 20. Productive compartment types.

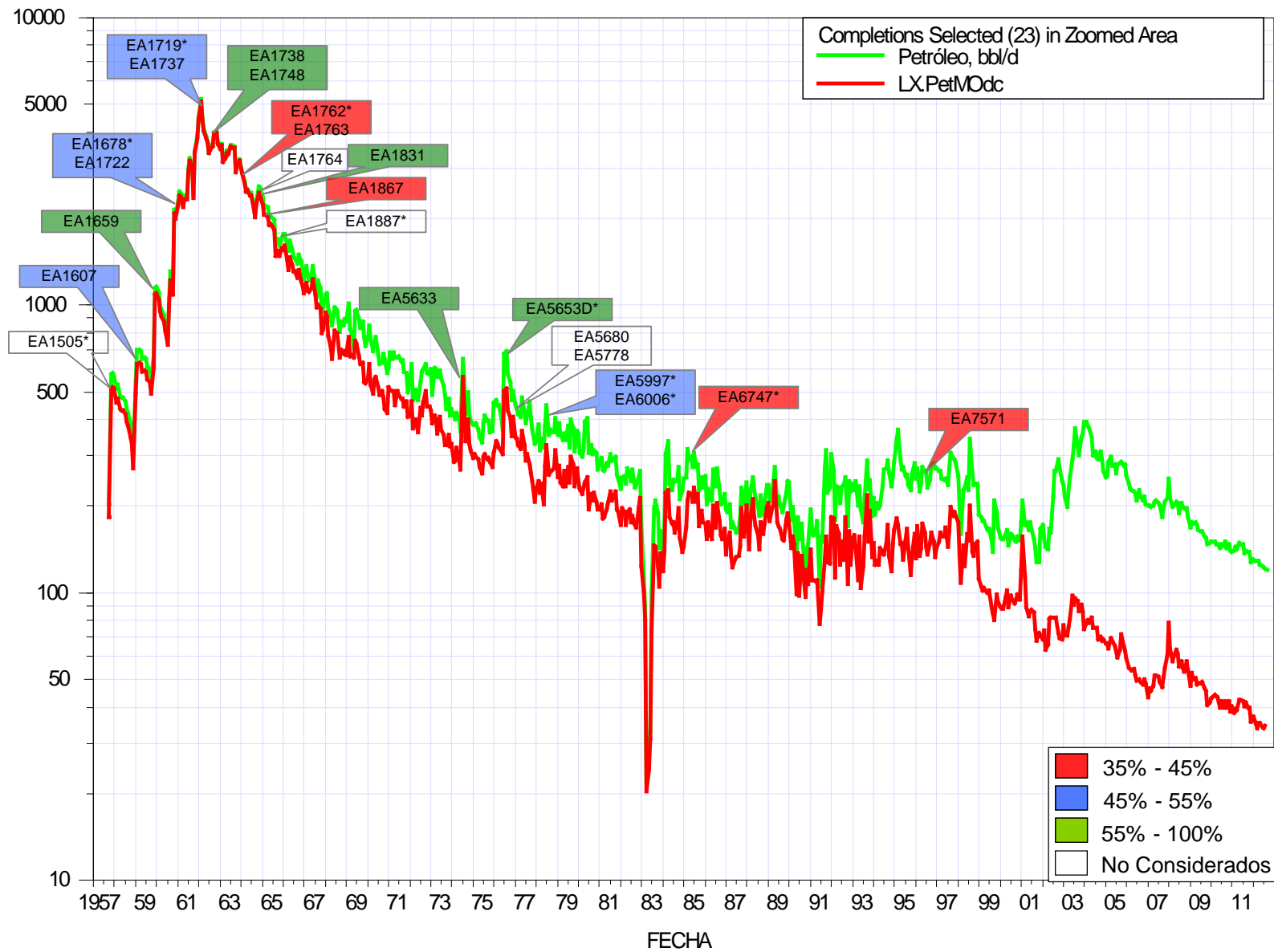Figure 21. Distribution types and compartment curves.

Figure 22. Declination curves for all wells show fracture production in the first years of production.

$$POIS = 7758 \frac{A * H * PHIE * So}{Boi}$$

$$POIS\,f = 7758 \frac{A * (\#F * Ap) * H * PhieF * So}{Boi} \qquad PhieF * SO \approx 0.7$$

$$POIS\,f = 7758 \frac{A * (DFracA * Ap) * PhieF * So}{Boi} \qquad PhieF * SO \approx 0.7$$

Dens de Fracturas = Long de Fracturas / Area

Vol. Fracturas = Long de Fracturas * Apertura / Area
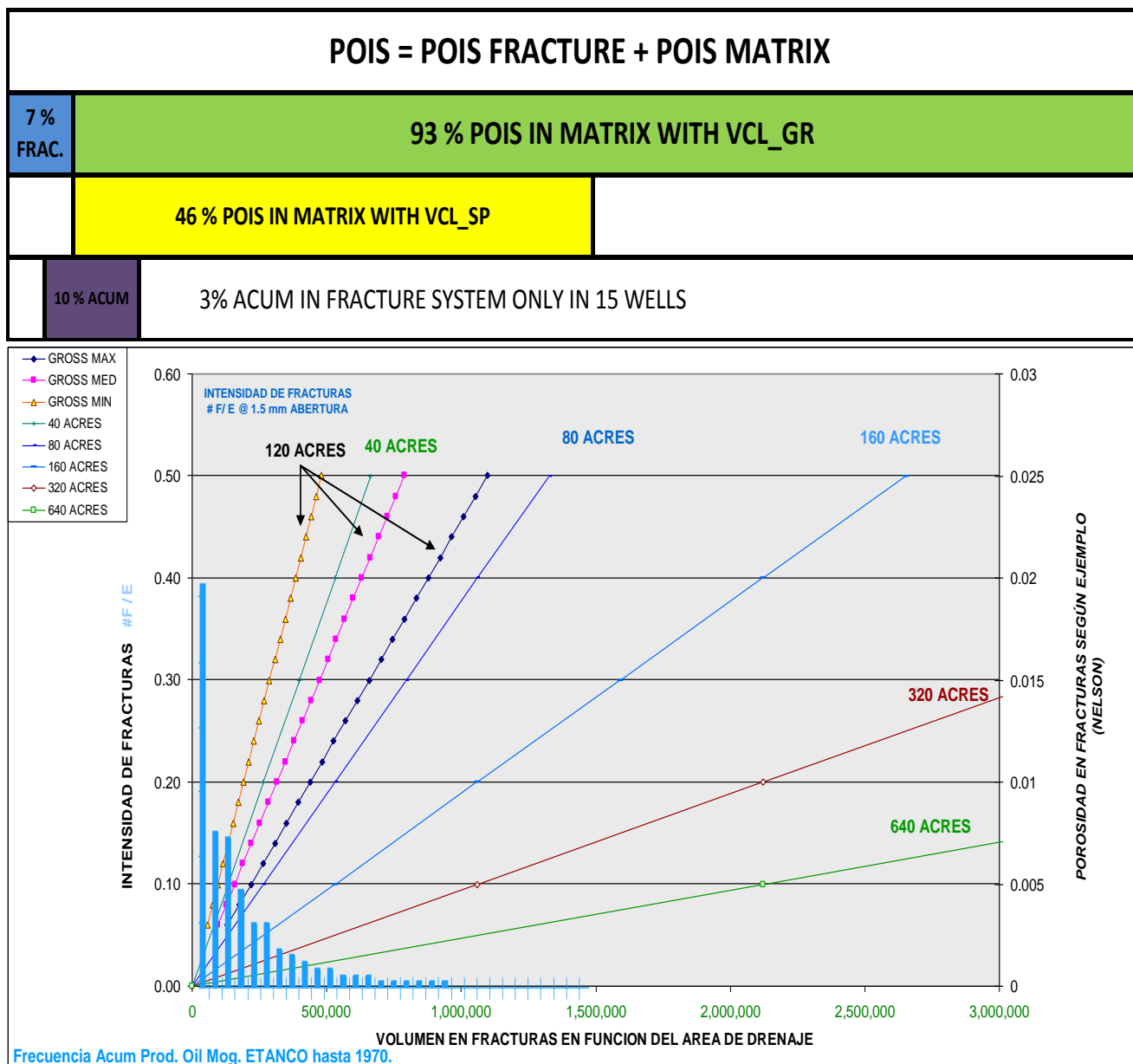
Figure 23. Calculation of fracture volumes.

Figure 24. Calculation of matrix volumes.

POZO	ZoneName	Gross	Net	AvPhi	AvSw	PhiSo*H	
EA1737	MOGOLLON	346	80	0.04	0.57	1.42	VCL(GR-RES)
EA1737	CHORRO_INFERIOR	212	86	0.04	0.53	1.49	VCL(GR-RES)
EA1737	FUENTE	674	93	0.04	0.61	1.41	VCL(GR-RES)
EA1737	MOGOLLON	346	40	0.04	0.57	0.7	VCL(SPBL)
EA1737	CHORRO_INFERIOR	212	28	0.04	0.49	0.54	VCL(SPBL)
EA1737	FUENTE	674	32	0.04	0.62	0.46	VCL(SPBL)
EA1748	MOGOLLON	383	113	0.04	0.42	2.71	VCL(GR-RES)
EA1748	CHORRO_INFERIOR	207	24	0.04	0.35	0.54	VCL(GR-RES)
EA1748	FUENTE	650	147	0.04	0.37	3.57	VCL(GR-RES)
EA1748	MOGOLLON_INFERIOR	1018	20	0.05	0.47	0.52	VCL(GR-RES)
EA1748	MOGOLLON	383	42	0.04	0.42	1	VCL(SPBL)
EA1748	CHORRO_INFERIOR	207	14	0.04	0.38	0.3	VCL(SPBL)
EA1748	FUENTE	650	55	0.04	0.35	1.31	VCL(SPBL)
EA1748	MOGOLLON_INFERIOR	1018	20	0.05	0.47	0.52	VCL(SPBL)

Table 1. Summary to petrophysical parameters for different VCL curves.

CLASIF.	POZO	APORTE FRACTURA (MBLS)
35-45%	EA1762	172.14
	EA7571	11.46
	EA6747	30.85
	EA1763	85.45
45-55%	EA1607	475.63
	EA1678	137.54
	EA6006	24.50
	EA1719	320.19
	EA1722	266.33
	EA1737	243.89
	EA5997	14.73
55-100%	EA1659	893.06
	EA1738	454.60
	EA1748	75.90
	EA1831	179.06
	EA5653D	21.09
	EA5633	44.77

Table 2. Fracture Oil production for well.